Phosphorus removal from waste water by chemical precipitation

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In order to limit or prevent eutrophication in Lake Maryut, phosphorus discharge with wastewater from the Eastern Sewage Treatment Plant must be reduced. Because the secondary treatment proposed for this plant will not achieve reasonable nutrient removal unless certain modifications are made. The most economical option is upgrading the plant by implementing chemical precipitation. Four chemical coagulants: Alum; Lime; Lime +5% seawater; and Ferric Chloride were used in this study under different settling times. The results of this research showed that alum dose of 250 mg/l and settling time of 30 min achieved residual phosphorus of 1.77 mg P/l and % removal of COD, BOD, and SS of 44.2, 38.3, and 35.8, respectively. Lime dose of 350 mg/l and settling time of 120 min. achieved residual phosphorus of 2.3 mg P/l and COD, BOD, SS % removal 65.2, 67, and 66.6, respectively. Lime+5% seawater dose 350 mg/l and settling time 90min. achieved residual phosphorus of 1.83 mg P/l and COD, and SS 68.6 and 75.1%. Ferric chloride dose of 90 mg/l and settling time 30 min. achieved residual phosphorus of 1.73 mg P/l and % removal of COD, BOD, and SS 46.6, 47.1, and 64.2, respectively.

تقوم محطة التنقية الشرقية بالإسكندرية بمعالجة حوالي ٤١٠ ألف متر مكعب/يوم من المخلفات السائلة معالجة ابتدائية قبل صرفها على بحيرة مريوط. ونظر لاحتواء هذه المخلفات على تركيزات عالية من المغذيات بالإضافة إلى الحمل العضوي المرتفع فقد حدث نمو عشبي ذائد Eutrophic في البحيرة وأصبحت المياه ملوثة بدرجة كبيرة. ويعتبر النتروجين والفوسفور من أهم المغذيات للنمو العشبي الذائد وحيث أن بعض الطحالب يمكنها تثبيت النتروجين الجوي فانه يفضل كسر السلسة الغذائية عن طريق الفوسفور ولذلك تعتبر إزالة الفوسفور هي الأكثر فعالية. ومن المتوقع أن يتم في المستقبل إضافة مرحلة معالجة ثانوية للمحطة الشرقية ولكن لن يمكن الوصول بهذه المرحلة إلى الحدود المطلوبة من الفوسفور والنيتروجين إلا إذا أجريت تعديلات هامة على عملية المعالجة. مع العلم بأن إزالة الفوسفور بيولوجيا تعتبر عملية معقدة وصعبة. ولذلك فان البديل الاقتصادي هو الترسيب الكيماوي. ويهدف هذا البحث إلى دراسة كفاءة الترسيب الكيماوي على إزالة الفوسفور من المخلفات السائلة للمحطة الشرقية بالإسكندرية. وقد تم إجراء تجارب معملية على عينات من هذه المحطة باستخدام ٤ مروبات مختلفة و٣ أزمنة ترسيب بهدف الوصول إلى الجرعات المثلى لإزالة الفوسفور وكذلك تحديد كفاءة إزالة من الأكسجين الحيوي المستهلك والأكسجين الكيميائي المستهلك والمواد الصلبة العالقة لكل حالة.

Keywords: Wastewater treatment, Chemical precipitation, Coagulants, Phosphorus removal.

1. Introduction

Sanitary Engineering technology was developed to the extent where it became economically, socially and politically feasible to treat the wastewater so as reduce its adverse impact on watercourses and environment. When considering pollution by wastewater there are of course other effects than the creation of dissolved oxygen (DO) deficits. Depending on the dilution available there will be significant increase in the dissolved solids, organic content, nutrients such Nitrogen and Phosphorus, color and turbidity. All of these constituents may give rise to undesirable changes in water quality. Nutrient build-up is a serious problem in lakes. Eventually, as nutrient levels increase, the water becomes nutrient-rich or eutrophic. In extreme cases the water may become heavily polluted by vegetation.

Accelerated eutrophication of surface waters, especially lakes, is one of the prime concerns of environmentalists. Complete removal of all nutrients by present biological or physical treating methods is not possible with present technology. Nitrogen and phosphorus are essential for plant growth. If we can reduce one to a low enough

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concentration the food chain is broken, and growth is controlled.

Breaking the food chain by nitrogen reduction is not particularly favored because of the ability of some algae, especially the very objectionable blue-greens, to fix atmospheric nitrogen. Although phosphorus is not high in the algal nutrient chain, [the carbon: nitrogen: phosphorus ratio requirement of 100 : 20 : 1] its removal is the preferred method of breaking the food chain [1].

Phosphorus in wastewater may be present in three forms: orthophosphate, polyphosphate, and organic phosphorus. Typically, the phosphorus enters the wastewater from human body wastes, from food wastes discharged to sewers from kitchen grinders, and from the condensed inorganic phosphate compounds used in various household detergents. Commercial washing and cleaning compounds are also a source of phosphates.

Phosphorus removal may be considered as a transfer of both suspended and soluble forms of phosphorus originally present in raw sewage from that sewage to the sludge formed in the primary clarifiers. This transfer is affected by chemical addition, which precipitates soluble phosphorus, coagulates suspended solids and incorporates the phosphorus-rich solids into the primary sludge. The primary effluent flowing from the clarifier is thus relatively low in phosphorus.

Generally, total phosphorus removal down to an effluent guideline of 2 mg/l can be achieved by primary or simultaneous precipitation (addition of chemicals to the aeration tank). Post-phosphorus precipitation (chemical addition to the secondary effluent) only becomes necessary when more stringent effluent phosphorus levels are advised [2].

In Alexandria, which can be considered as the second largest city in the Middle East with regards to population as well as industrial activities, the Eastern Sewage Treatment Plant [ESTP] produces 410 000 m^3/d [3], the effluent of the treatment plant is discharged into the Lake Maryut. The effect is eutrophication caused by heavy growth of algae with a subsequent, unwanted disturbance of the ecological balance of the recipient. A consequence is, for example, that the living conditions for fish are deteriorated due oxygen depletion.

In order to limit or prevent eutrophication, the phosphorus discharged with the wastewater must be reduced. At present, the ESTP consists of only primary treatment, which is not enough to achieve the recommended levels of the different contaminants such as BOD, COD, suspended solids, nitrogen, and phosphorus. There is no doubt that secondary treatment is required to improve effluent quality. However, secondary treatment will not achieve reasonable nutrient removal unless certain modifications are implemented. It is well known that biological phosphorus removal is a sophisticated process, and very difficult to operate and control.

The continuous need or demand under the conditions usually existing in developing countries, such as our local conditions where rates of population increase demanding continuous increase in facilities and services. In these countries there is shortage or limited available funds, priorities imposed and the limitations of skilled personnel in addition to poor management, under such conditions the solution could lie in upgrading the capacity of the existing facilities or upgrading their performance.

For Alexandria, an economical option is upgrading the treatment plants in order to implement chemical treatment. One major advantage of chemical precipitation is to control phosphorus level that has a significant effect on the eutrophication in Lake Maryut. Moreover, improvements in effluent quality can also be achieved.

The major aim of this research is to carry out phosphorus removal treatability study, in order to determine the efficiency of different chemical precipitants with different dosages on the raw sewage, upstream the primary treatment to reach minimum residual phosphorus, and higher removal efficiency of COD, BOD, and suspended solids. For the sake of this aim, chemical precipitants such as Alum, Lime, Lime + 5% sea water, and $FeCl_3$ were used to react with the soluble phosphorus in the wastewater and to convert it into insoluble phosphorus which precipitates easily in the settling tank.

2. Materials and methods

2.1. Chemicals used for precipitation

A variety of metal salts are used for removal of phosphorus from municipal wastewater. The reactions between phosphorus and metal salts are complex. It is assumed that the primary mechanism of phosphorus removal is interaction of the metal ion with orthophosphate to form an insoluble precipitate. It is recommended that any engineering examination of chemical addition for phosphorus removal should include a jar test of the actual wastewater of concern. This will avoid the common error of assuming a required dosage, when the actual dosage can vary substantially between facilities. The metal salts used for the purpose of this study are:

1. Alum: The commercial product of alum (Aluminum Sulfate), $Al_2(SO_4)_3.18H_2O$ contains; aluminum (Al) 8.1% by weight, sulfate (SO_4) 43.2% by weight, and water crystallization (H_2O)48.7% by weight. In this study, alum doses from 150 to 350 mg/l were used. The reaction between aluminum and phosphate can be simplified as:

$$Al^{3+} + PO_4^{3-} \rightarrow AlPO_4^{-}$$

On a mole basis, 1 mole of Al reacts with 1 mole of P.

2. Lime: Hydrated lime [$Ca(OH)_2$] was used in this study. The molecular weight is 74.08. The Calcium ion reacts with phosphate ion in the presence of hydroxyl ion to form hydroxyapatite [4]. The composition of this material may be variable, but an approximate equation for its formation can be written as follow:

$$3\ HPO_4^{\ 2-} + 5\ Ca^{2+} + 4\ OH^- \rightarrow Ca_5(OH)(PO_4)_3^{-} + 3H_2O$$

In this study, lime doses ranging from 150 to 350 mg/l were tested.

3. Lime + 5% Seawater: This type of process is not very common. However, it is widespread in Norway for example [5]. $Ca(OH)_2$ can be used in combination with 3-5% seawater in relation to the volume of wastewater. Magnesium in the sea water functions as an auxiliary coagulant, which saves Ca $(OH)_2$. In this study, (lime + 5% seawater) doses ranging from 150 to 350 mg/l were tested. The addition of 5% of seawater by volume is applied to the prepared solution of 20 g/l of lime.

4. Iron salt: The chemical reaction of phosphate removal with Fe^{3+} is expressed by the following equation:

$$Fe^{3+} + PO_4^{3-} \rightarrow Fe\ PO_4^{-}$$

The equation simply indicates that 1.0 mole of Fe^{3+} will precipitate 1.0 mole of phosphate. The theoretical mole ratio of Fe^{3+}: PO_4^{3-} as mentioned above is 1:1, but the practical mole ratio was higher than this value.

In this study, ferric chloride doses ranging from 45 to 90 mg/l as ferric ion were tested. The solution was prepared in concentration of 10 mg/l and iron is determined gravimetrically as ferric oxide.

2.2. Wastewater

Raw sewage samples were collected from a fixed point in the Eastern Treatment Plant, at the head work structure after screens and grit removal, and before entering the primary sedimentation tanks. Sampling time was also fixed to 8.30 A.M. Samples of wastewater were taken in 2 plastic 20 liter-container. Before taking samples for the test the container was put on its side and rolled backwards and forwards vigorously, to mix the contents.

The major 3 samples were taken at three intervals of time and named Raw I on [18 - 7- 1998]. Raw II on [1 - 8 – 1998], and Raw III on [15 - 8 - 1998], table 1 shows the characteristics of the 3 major samples. Each set of jar test experiments were performed on each collected sewage sample by using each coagulant dose two times and the average of the two runs were then recorded. The characteristics of the 3 major samples are shown in table 1.

Table 1
Characteristics of the 3 raw sewage samples

Sample, Date	pH	COD	BOD	SS
Raw (I) 18 – 7 - 1998	7.1	447	249	400
Raw (II)1 - 8 - 1998	7.9	320	200	327
Raw (III) 15 – 8 - 1998	7.4	378	240	379

2.3. Experimental plan

Tests were carried out on the grab samples of the raw sewage after adding varying dosages of the selected coagulants. The used coagulant doses were as follows:

- Alum doses of 150, 200, 250, 300, and 350 ppm.
- Lime doses of 150, 200, 250, 300, and 350 ppm.
- Lime + 5% sea water doses of 150, 200, 250, 300, and 350 ppm.
- Ferric chloride doses of 45, 56, 67, 78, and 90 ppm.

All bench tests were conducted in the following manner: Samples of wastewater were stirred at 100 rpm for approximately 5 minutes, followed by gentle mixing at 25 rpm for 15 minutes. Coagulants were added during the rapid mix period. The treated samples were allowed to settle for 30, 90, and 120 minutes before analyses were made.

Total phosphorus (P-total), Biochemical Chemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), pH, and Suspended Solids (SS) were the parameters determined for the influent wastewater to the primary treatment and the effluent samples from every jar (after dosing the coagulant, rapid mixing, slow mixing, and settling). All parameters were determined in accordance with the American Standards Methods for the Examination of Water and Wastewater [6]. The measured parameters of each sample and the average of the three samples were recorded.

3. Results and discussion

As stated before, this study aims to investigate the feasibility of chemical precipitation upstream the primary treatment in order to achieve minimum phosphorus residual and higher removal of COD, BOD, and suspended solids in the effluents of the Eastern Treatment Plant of Alexandria (which applies only primary treatment). This was accomplished by the addition of chemical precipitants such as iron, aluminum salts and lime to the influent of the primary treatment tank.

Because the wastewater has the nature of fluctuation in its characteristics, the initial parameters for every sample are variable. To detect the relation between coagulant dosages and different parameters, the averages of the three samples results are presented and discussed. It should also be indicated that the recorded results of each sample are average of two measurements.

Three different settling times (30, 90, and 120 minutes) were selected for each coagulant dose to detect the time effect on coagulation. This would allow the operator to make a compromise between the time effect and the coagulant doses on phosphorus removal efficiency.

3.1. Relation between coagulant dose and residual phosphorus concentration

3.1.1.Alum

Table 2 gives a summary of the effect of adding different doses of alum. The relationship between alum dose, settling time and residual phosphorus is also shown in fig1.

From table 2 and fig.1, it is clear that increasing alum dose improves phosphorus removal. After 30 min settling alum dose of 200 mg/l results in phosphorus removal efficiency of 70.8 %, while using 250 mg/l dose results in 79.9 % (residual phosphorus 1.77 mg P/l, i.e., lower than the recommended guideline of 2 mg P/l). Increasing the dose to 300 mg/l results in slight improvement (only 3.4 %, from 79.9 to 83.3 %).

Table 2 also indicates that, increasing the settling time to 90 min, using alum dose of 250 mg/l, results in improving the removal efficiency. (about 1.5 % from 79.9 to 81.4 %). From the same Table, increasing the settling time to120 min using the same dose of 250 mg/l, results in better removal efficiency (about 2.7 % from 79.9 to 82.6 %).

From these results it can be concluded that, alum dose of 250 mg/l and settling time of 30 min can achieve residual phosphorus within the recommended guidelines. Increasing the settling time results in better removal efficiency, but larger sedimentation tank volume is also needed.

3.1.2. Lime

The effect of lime addition is shown in table 3 and fig. 2. From fig. 2 it can be

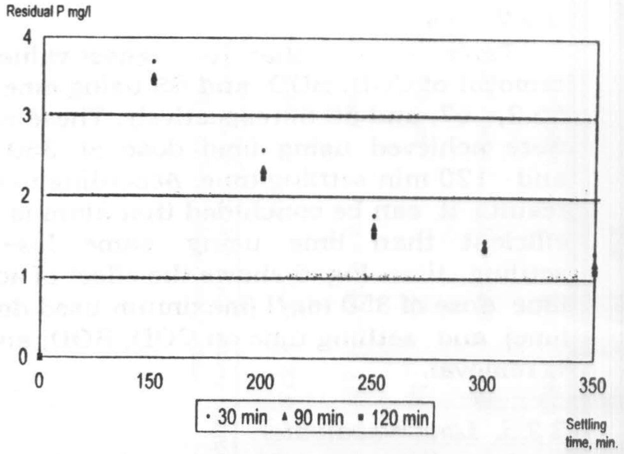

Fig. 1. Effect of alum dose and settling time on residual P.

indicated that increasing lime dose also improves phosphorus removal. After 30 min settling and using lime dose of 350 mg/l (the higher dose used) results in phosphorus removal of 70.5 % with residual phosphorus of 2.6 mg P/l. This concentration of the residual phosphorus is not complying with the required target.

Also table 3 and fig.2 show that, increasing the settling time to 90 min with the same dose of 350 mg/l, results in slight improvement in the removal efficiency (only 2.6% from 70.5 to 73.1%) with residual phosphorus of 2.37 mg P/l.

Increasing the settling time to 120 min using the same dose of 350 mg/l, results also in slight improvement in the removal efficiency (about 3.4% from 70.5 to 73.9%) with residual phosphorus of 2.3 mg P/l. This residual phosphorus is approximately near the standard limit.

These results show that on using lime addition, reaching the required target (2 mg P/l) is very difficult through the selected dose range even with increasing settling time to 120 minutes.

3.1.3. *Lime + 5% seawater*

As mentioned before, mixing lime with 5% seawater is not a very common trend of treatment but it is used widely in coastal areas. The benefit of seawater addition to lime is to lower the residual phosphorus according to the fact that magnesium in the seawater functions as an auxiliary coagulant, also it decreases the quantity of added lime, both of which reducing the pH.

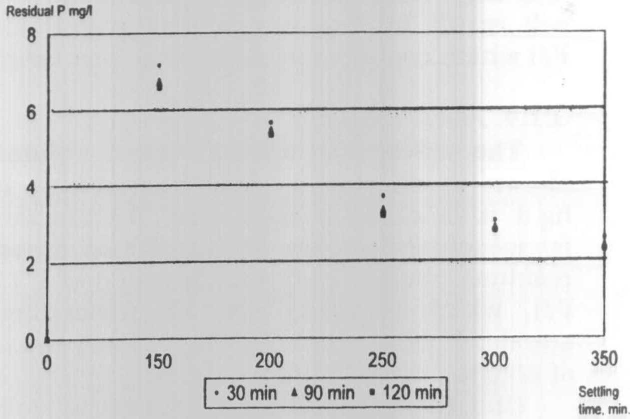

Fig. 2. Effect of lime dose and setting time on residual P.

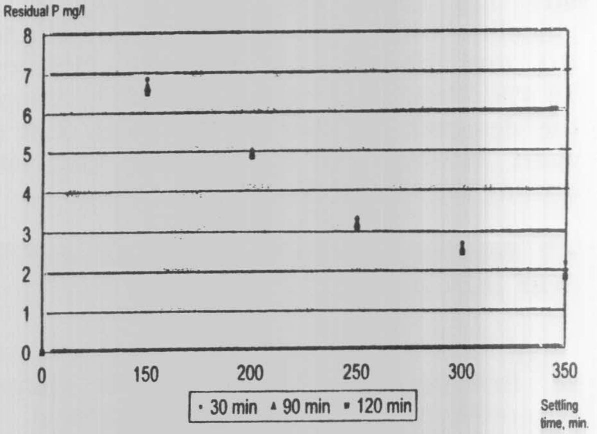

Fig. 3. Effect of lime + seawater dose and settling time on residual P.

From table 4 and fig.3, it is obvious that as the average dose of (lime + 5% seawater) increases, the residual P concentration decreases. After 30 min settling time lime + 5% seawater dose of 350 mg/l results in phosphorus removal efficiency of 75.3%, with residual phosphorus of 2.17 mg P/l which is near to the required target. Using the same dose and increasing the settling time to 90 min results in a considerable improvement in phosphorus removal efficiency (about 3.9% from 75.3% to 79.2%), with residual phosphorus concentration of 1.83 mg P/l that complies with the required target.

The same Table also indicates that increasing the settling time to 120 min using the same dose (350 mg/l), results in a very slight improvement in removal efficiency than the time of 90 minutes settling (about 0.4% from 79.2% to 79.6%).

From these results it can be concluded that when using Lime + 5% sea water, with a 350 mg/l dose and settling time of 90 minutes will result in residual phosphorus of 1.8 mg P/l which complies with the required target.

3.1.4. Ferric Chloride

The effect of adding ferric chloride is shown in shown in table 5 and fig.4. From fig.4 it is obvious that after 30 min settling ferric chloride dose 90 mg/l could achieve residual phosphorus concentration of 1.73 mg P/l, which complies with the recommended standard with phosphorus removal efficiency of 80.3%.

On the other hand, decreasing dose to 78.8 mg/l and increasing the settling time to 90 min could also achieve the effluent guideline with residual phosphorus of 1.9 mg P/l and phosphorus removal efficiency of 78.4%. Here, a decision should be taken by the designer whether to use high dose with short settling time or low dose with longer settling time (table 5).

4.2. Relation between coagulant dose and COD, BOD, and SS

Although the major aim of this study was to investigate the feasibility of chemical precipitation on phosphorus removal, the effect chemical addition on COD, BOD, and SS was also studied.

3.2.1. Alum

From table 2 it is obvious that, increasing both alum dose and settling time result in increasing the % removal of COD, BOD, and SS. The highest values of % removal of COD, BOD, and SS were 76.4, 73.9, and 62.5 respectively. These values were achieved using alum dose of 350 mg/l and 120 min settling time. fig.5 shows that for alum dose of 250 mg/l (selected dose to achieve residual phosphorus 1.77 mg P/l) the COD, BOD, and SS % removal efficiencies were 44.2, 38.3, and 35.8 respectively for settling time 30 min. For the same dose increasing the settling time would also increase the % removal of the 3 parameters.

3.2.2. Lime

Table 3 shows that, the highest value of % removal of COD, BOD, and SS using lime were 65.2, 67, and 66.6, respectively. These values were achieved using lime dose of 350 mg/l and 120 min settling time. According to these results it can be concluded that alum is more efficient than lime using same dose and settling time. Fig. 6 shows the effect of adding lime dose of 350 mg/l (maximum used dose of lime) and settling time on COD, BOD, and SS % removal.

3.2.3. Lime + seawater

According to table 4, using lime +5% seawater resulted in better removal efficiencies than using lime alone, for all measured parameters. From fig.7 the highest values of % removal of COD, BOD, and SS using lime +5% seawater were achieved with does of 350 mg/l and 120 min. settling time. These values were 73.8, 68.6, and 76.7, respectively.

For Lime + 5% seawater dose of 350 mg/l and 90 min. settling time (selected dose to achieve residual phosphorus 1.8 mg P/l) the COD, and SS % removal efficiencies were 68.6, and 75.1, respectively.

3.2.4. Ferric Chloride

Table 5 shows that increasing both ferric chlorides does and settling time resulted in improving the % removal of COD, BOD, and SS. The highest values of % removal of COD, BOD, and SS were 58.9, 61.3, and 73.4, respectively. These values were achieved using ferric chloride dose of 90 mg/l and 120 min. settling time. Fig.8 shows that for ferric dose of 90 mg/l and 30 min. settling time (selected dose to achieve residual phosphorus 1.73 mg P/l) the COD, BOD, and SS % removal efficiencies were 46.6, 47.1, and 64.2, respectively.

Finally, fig.9 shows the effect of using maximum experimented doses with maximum settling time on COD, BOD, and SS% removal. According to fig.9, the use of alum resulted in achieving highest values of COD, and BOD % removal (76.4, and 73.9, respectively), while the use of lime +5% seawater resulted in achieving highest value of SS % removal (76.6).

Table 2
Summary of the effect of alum addition on COD, BOD, SS, and Phosphorus removal

Raw Sewage	30 minutes Settling							90 minutes Settling						120 minutes settling					
	S*	C**	1	2	3	4	5	C	1	2	3	4	5	C	1	2	3	4	5
Dosage, mg/l		-	150	200	250	300	350		150	200	250	300	350	-	150	200	250	300	350
PH	7.47	7.47	6.87	6 67	6.57	6.47	6.37						-	-	-	-	-	-	-
COD	382	287	224	222	213	191	172	220	188	146	129		122	193	151	119	104	103	90
% COD Reduction	-	24.9	41.4	41.9	44.2	50	55	42.4	50.8	61.8	66.2	-	68	49.4	60.5	68.8	72.8	73	76.4
BOD	230	182	142	147	142	113	110		-	-	-	-	-	117	98	83	67	70	60
% BOD Reduction		20.9	38.3	36.1	38.3	50.9	52.2		-	-	-	-	-	49.1	57.4	63.9	70.9	69.6	73.9
Suspended Solids	369	289	263	255	237	-	202	263	224	195	181	179	167	252	194	171	168	154	139
% SS Reduction		21.7	28.7	30.9	35.8	-	45.4	28.7	39.3	47.2	50.9	51.5	54.7	31.7	47.4	53.6	54.5	58.2	62.5
P Conc , mg/l	8.8	8.47	3.7	2.57	1.77	1.47	1.33	8.3	3.5	2.33	1.63	1.4	1.2	8.27	3.43	2.23	1.53	1.37	1.1
% P Reduction		3.8	57.9	70.8	79.9	83.3	84.9	5.7	60.2	73.5	81.4	84.1	86.4	6.1	61	74.6	82.6	84.5	87.1

- * S: Raw sewage sample without adding coagulants or settling.
- **C: Control without adding coagulants.

Table 3
Summary of the effect of lime addition on COD, BOD, SS, and Phosphorus removal

Raw Sewage			30 minutes Settling					90 minutes Settling						120 minutes settling					
	S*	C**	1	2	3	4	5	C	1	2	3	4	5	C	1	2	3	4	5
Dosage, mg/l	-	-	150	200	250	300	350	-	150	200	250	300	350	-	150	200	250	300	350
PH	7.47	7.47	8.77	8.87	9.07	9.27	9.47		-	-		-	-	-	-	-	-	-	-
COD	382	323	266	218	237	220	187	298	197	-	196	167	147	283	195	157	193	153	133
% COD Reduction	-	15.5	30.4	42.9	38	42.4	51.1	22	48.4	-	48.7	56.3	61.5	25.9	49.9	58.9	49.5	60	65.2
BOD	233	210	177	150	163	147	120	-	-	-	-	-	-	170	130	103	120	103	77
% BOD Reduction	-	9.8	24	35.6	30	36.9	48.5	-	-	-	-	-	-	27	44.2	55.8	48.5	55.8	67
Suspended Solids	369	279	210	231	187	183	160	261	208	175	173	157	138	237	187	155	153	138	123
% SS Reduction	-	24.4	34.6	37.4	49.5	50.1	56.7	29.3	43.7	52.4	53.1	57.5	62.6	35.8	49.2	57.9	58.5	62.5	66.6
P Conc. , mg/l	8.8	8.57	7.17	5.67	3.7	3.07	2.6	8.37	6.73	5.43	3.33	2.87	2.37	8.3	6.6	5.33	3.2	2.8	2.3
% P Reduction	-	2.6	18.5	35.6	58	65.1	70.5	4.9	23.5	38.3	62.1	67.4	73.1	5.7	2.5	39.4	63.6	68.2	73.9

- * S: Raw sewage sample without adding coagulants or settling.
- **C: Control without adding coagulants.

Table 4
Summary of the effect of lime +5% seawater addition on COD, BOD, SS, and Phosphorus removal

Raw Sewage			30 minutes Settling					90 minutes Settling						120 minutes settling					
	S*	C**	1	2	3	4	5	C	1	2	3	4	5	C	1	2	3	4	5
Dosage, mg/l			150	200	250	300	350	·	150	200	250	300	350	·	150	200	250	300	350
PH	7.47	7.47	8.67	8.87	9.0	9.1	9.27		-		-	-		-	-	-	·	-	-
COD	382	313	235	227	187	160	147	283	205	167	147	133	120	275	185	147	133	123	100
% COD Reduction		18.1	38.5	40.6	51.1	58.1	61.5	25.9	46.3	56.3	61.5	65.2	68.6	28.0	51.6	61.5	65.2	67.8	73.8
BOD	233	200	187	143	123	107	93	·	·	-	-	-	·	163	120	97	88	77	70
% BOD Reduction		10.3	16.1	35.9	44.8	52	58.3		-	-	-	-	-	26.9	46.2	56.5	60.5	65.5	68.6
Suspended Solids	369	257	218	178	174	164	117	249	175	129	108	100	92	218	121	106	102	94	86
% SS Reduction		30.4	40.9	51.8	52.9	55.6	68.3	32.5	52.6	65	70.7	72.9	75.1	41	67.2	71.3	72.4	74.5	76.7
P Conc. , mg/l	8.8	8.57	6.87	5.03	3.33	2.67	2.17	8.3	6.67	4.93	3.17	2.53	1.83	8.3	6.53	4.87	3.07	2.43	1.8
% P Reduction		2.6	21.9	42.8	62.2	69.7	75.3	5.7	24.2	44	64	71.3	79.2	5.7	25.8	44.7	65.1	72.4	79.6

- * S: Raw sewage sample without adding coagulants or settling.
- **C: Control without adding coagulants.

Table 5
Summary of the effect of ferric chloride addition on COD, BOD, SS, and Phosphorus

Raw Sewage	30 minutes Settling							90 minutes Settling						120 minutes settling					
	S	C	1	2	3	4	5	C	1	2	3	4	5	C	1	2	3	4	5
Dosage, mg/l	-	-	45	56	67	78	90	-	45	56	67	78	90	-	45	56	67	78	90
PH	7.47	7.47	8.67	8.87	9.0	9.1	9.27	-	-	-	-	-	-	-	-	-	-	-	-
COD	382	299	248	238	219	210	204	252	220	232	190	180	173	245	198	184	177	167	157
% COD Reduction	-	21.7	35.1	37.7	42.7	45	46.6	34.0	42.4	39.3	50.3	52.9	54.7	35.9	48.2	51.8	53.7	56.3	58.9
BOD	233	187	160	147	133	133	127	-	-	-	-	-	-	157	120	107	87	100	93
% BOD Reduction	-	22.1	33.3	38.8	44.6	44.6	47.1	-	-	-	-	-	-	34.6	50	55.4	63.8	58.3	61.3
Suspended Solids	369	266	235	191	183	179	132	255	201	161	147	143	120	219	174	132	-	121	98
% SS Reduction	-	27.9	36.3	48.1	50.4	51.4	64.2	30.9	45.5	56.3	60.3	61.1	67.5	40.7	52.7	64	-	67.3	73.4
P Conc. , mg/l	8.8	8.6	4.63	3.23	2.57	2.2	1.73	8.43	3.77	2.73	2.4	1.9	1.43	8.4	3.7	2.67	2.27	1.8	1.43
% P Reduction	-	2.3	47.4	63.3	78.4	76.1	80.3	4.2	57.2	69	72.7	78.4	83.7	4.5	58	69.7	74.2	79.6	83.7

- * S: Raw sewage sample without adding coagulants or settling.
- **C: Control without adding coagulants.

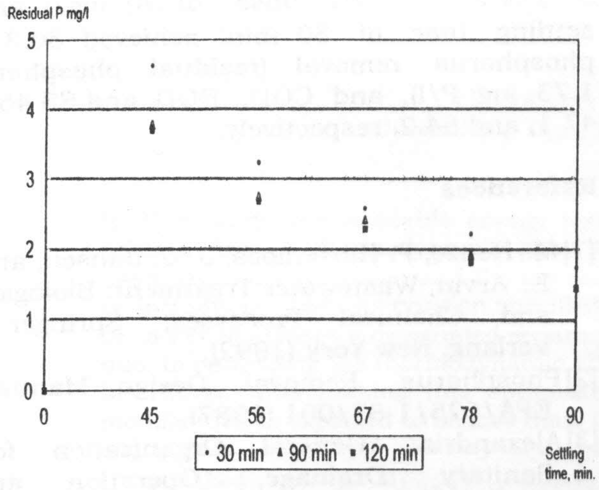

Fig. 4. Effect of ferric chloride dose and settling time on residual P.

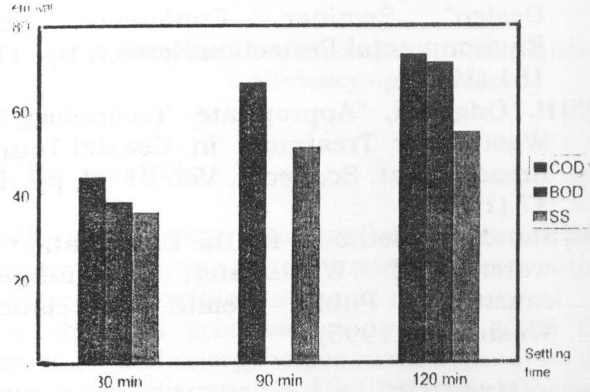

Fig. 5 The effect of alum dose (250mg/ l) and settling time on COD, BOD, and SS% removal.

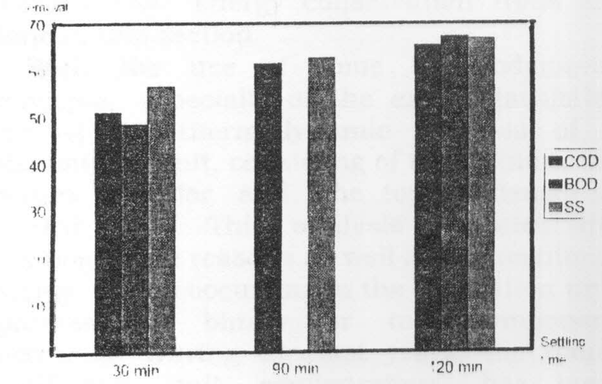

Fig 6 The effect of lime dose (350 mg/ l) and settling time on COD, BOD, and SS% removal.

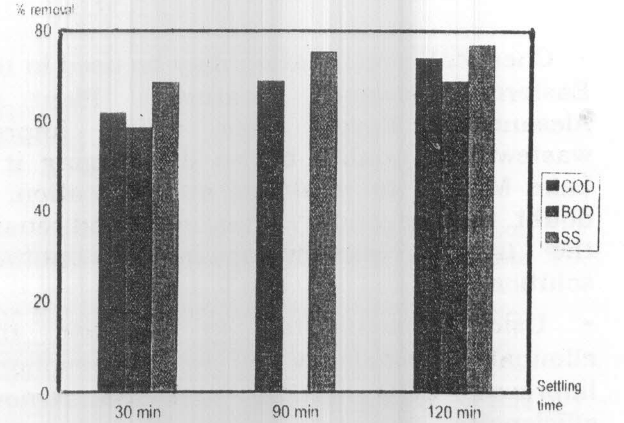

Fig. 7. The effect of lime + seawater dose (350 mg/ l) and settling time on COD, BOD, and SS% removal.

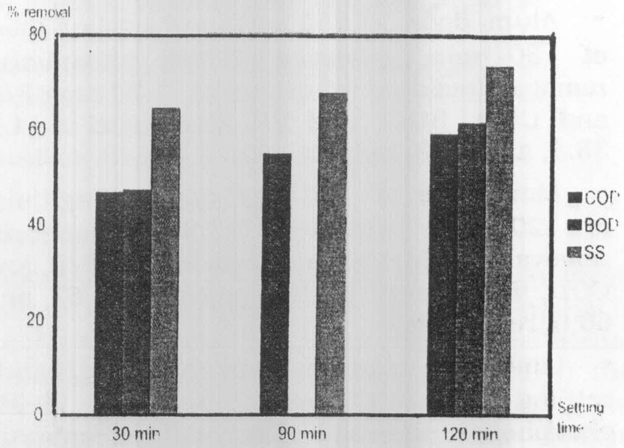

Fig. 8. The effect of ferric chloride dose (90 mg/ l) and settling time on COD, BOD, and SS% removal.

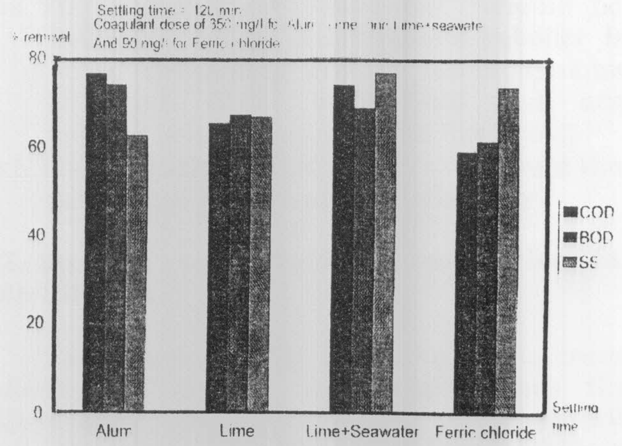

Fig. 9. The effect of adding max coagulant dose and max settling time on % removal of COD, BOD, and SS.

Conclusions

- Chemical precipitation may be used in the Eastern Sewage Treatment Plant in Alexandria, Egypt. This would improve wastewater quality before discharging it to Lake Maryut to minimize eutrophication. No doubt that secondary treatment and reusing the treated wastewater is the optimum solution.
- Using coagulants to increase the elimination efficiency of total phosphorus improves COD, BOD, and SS removal efficiencies.
- For the experimented coagulants the optimum doses were found as follows:
- Alum dose of 250 mg/l and settling time of 30 min. achieved 79.9% phosphorus removal (residual phosphorus 1.77 mg P/l), and COD, BOD, and SS % removal of 44.2, 38.3, and 35.8, respectively.
- Lime dose of 350 mg/l and settling time of 120 min. achieved 73.9% phosphorus removal (residual phosphorus 2.3 mg P/l), and COD, BOD, and SS % removal 65.2, 67, and 66.6, respectively.
- Lime + 5% seawater dose of 350 mg/l and settling time 90 min. achieved 79.2% phosphorus removal (residual phosphorus 1.83 mg P/l), and COD, SS % removal 68.6 and 75.1, respectively.
- Ferric Chloride dose of 90 mg/l and settling time of 30 min. achieved 80.3 % phosphorus removal (residual phosphorus 1.73 mg P/l), and COD, BOD, and SS 46.6, 47.1, and 64.2, respectively.

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